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November 22, 1961

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(NASA TMX-51527; MTP-TEST-61-20)

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ANTICIPATED RMS SOUND LEVELS AROUND STATIC TESTS OF LARGE VEHICLES

by
Richard N. Tedrick and Wade D. Dorland

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GEORGE C. MARSHALL SPACE FLIGHT CENTER

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ABSTRACT

Comparison is made between the over-all sound pressure levels around the static test firings of the Saturn and those calculated for the tests of 3-, 6-, 12- and 22-million-pound thrust vehicles. The third-octave acoustic spectra are calculated for each vehicle size.

The effects of both the inverse square law and the excess attenuation were determined and graphs are presented showing both over-all and spectral sound pressure levels at a 50,000-foot range for the large boosters.

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TEST DIVISION

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SUMMARY

Comparison is made between the over-all sound pressure levels around the static test firings of the Saturn and those calculated for the tests of 3-, 6-, 12- and 22-million-pound thrust vehicles. The third-octave acoustic spectra are calculated for each vehicle size.

The effects of both the inverse square law and the excess attenuation were determined and graphs are presented showing both over-all and spectral sound pressure levels at a 50,000-foot range for the large boosters.

SECTION I. INTRODUCTION

One of the by-products of the static test firings of the Saturn vehicles at Marshall Space Flight Center was a high ambient noise level. This noise level was propagated across the Redstone Arsenal area and into the surrounding civilian communities. As a result of the meteorological factors at the time of firing, part of this acoustical energy was sometimes focused into the business and/or residential areas. Such occurrences have heightened the interest in determining what the effects may be of static firing larger rocket vehicles; whether they are to be fired at MSFC, or elsewhere. Therefore, utilizing the information garnered from the Saturn tests and accounting for the changes in the rocket sizes, spectra for the larger boosters have been calculated.

The major acoustical effect of testing larger boosters will not be the result of any spectacular rises in the over-all sound pressure level (SPL) at the source. Indeed, it is anticipated that the over-all SPL for the 22-million-pound thrust vehicle test will be only ten decibels (0.0002 microbar reference) over that for the Saturn. However, as a result of the much lower peak frequency, a larger proportion of the generated sound will be propagated over sound paths of several miles length (Fig.1).

SECTION II. CALCULATION OF INITIAL SOUND PRESSURE LEVELS

The anticipated power (P_m) of a rocket engine may be expressed (1) as:

$$P_m = 1/2\ MV^2 = 1/2\ \frac{w}{g}\ V^2 \qquad (1)$$

where M = mass flowrate in slugs per second. (A slug is defined as weight in pounds divided by the acceleration of gravity in feet per second per second.)

V = expanded jet velocity in feet per second

w = weight flowrate in pounds per second

g = acceleration of gravity in feet per second per second

For the F-1 engine, it is anticipated that P_m will equal approximately 6.5×10^9 watts. Since for most large rocket firings the acoustic efficiency has been found to be about 0.5 percent, it is reasonable to assume a similar efficiency for larger class vehicles tested under approximately equal conditions. Thus, the acoustic power of the F-1 engine may be expected to be 3.25×10^7 watts. (Ref. 1, page 43 for calculation method.) The acoustic power level, PWL, (10^{13} watts reference) is:

$$\text{PWL} = 10 \log (3.22 \times 10^7) + 130 \text{ db} = 205.0 \text{ db}. \qquad (2)$$

This amounts to a value of 153.5 db over-all sound pressure level at a 150-foot range. The C-1 configuration of the Saturn gave 152 db at a 150-foot range during test SA-03 on May 11, 1961. Considering the slight difference in thrust (1.3-million-pounds for C-1 and 1.5-million-pounds for F-1), this value is quite reasonable. The spectrum for the Saturn test is shown in Figure 2.

Considering that the C-3 class vehicle will consist of two F-1 engines, it may be seen that its acoustic power will be twice that of the F-1. Therefore, the anticipated sound power level for the C-3 is 208 db. This amounts to 156.5 db sound pressure level at a 150-foot radius. In the event of the test of a 6-million-pound thrust configuration, the acoustic power would be about 211 db OA PWL and the sound pressure level would be 159.5 db OA SPL. Raising the thrust from 6.0 to 7.5 million pounds would increase each level only 0.75 db.

Similarly, the OA PWL and the OA SPL for the 12-million-pound thrust Nova are 214 and 162.5, respectively. If a 22-million-pound thrust vehicle is developed, it has been estimated (Ref. 2 and 5) that it will result in a gain of about 10 db above the Saturn over-all sound pressure level.

If it is assumed (Ref. 3, page 658) that the peak frequency (f_{max}) in cycles per second of the noise spectrum is given by the following equation:

$$\frac{f_{max} d}{V} = \text{Constant}$$

(where d is the jet nozzle diameter in feet) and that V will not be changed by clustering engines, then the value of f_{max} is inversely proportional to d. Since it is assumed that the thrust is proportional to the number (N) of clustered engines, it follows that the thrust is also proportional to the total throat area (NA) of the engines.

Because: Area = πd^2,

$$d = \sqrt{\frac{NA}{\pi}}$$

Therefore d varies as the square root of the thrust and f_{max} is inversely proportional to the square root of the thrust.

The spectra for a 150-foot radius from vehicles larger than the Saturn are shown in Figures 3, 4, 5, and 6.

SECTION III. FAR-FIELD ACOUSTIC LEVELS

It was found empirically that the noise from the Saturn attenuated at a rate of approximately 4.0 db SPL per mile in excess of the inverse square law attenuation for at least the first 10 miles range. This figure corresponds to the excess attenuation which would be expected for a frequency of 80 cycles per second (Ref. 4). As can be seen from Figure 2, the peak frequency for the Saturn at a 150-foot range does occur at 80 cycles per second.

If the excess attenuation for sounds from each of the other large vehicles is likewise governed by the peak frequency of its mid-field spectrum, then it may be expected that the energy of the sound from the static firing of such vehicles will not attenuate at the same rate.

Generally, it has been found that the lower the frequency of a sound, the lower the propagation loss due to excess attenuation. Thus, the sound from large boosters will be propagated further as a result of the larger source energies and the lower attenuation of the atmosphere. Figure 1 shows the anticipated over-all sound pressure levels from large vehicles as a function of range from the test.

The calculated values of atmospheric attenuation were applied to the anticipated spectral curves for the large vehicles. Spectra then were calculated for a range of 50,000 feet from the source and they are shown in Figures 7 through 11. It should be remembered that these curves are for ideal meteorological conditions. Focal or shadow zone conditions might raise or lower the over-all sound pressure level by several decibels.

In order to test the validity of some of the assumptions upon which the above mentioned calculations were based, a portable frequency-modulated magnetic tape recording system was placed approximately 10,000 feet from the static test firing of a Saturn vehicle on May 5, 1961. Both the over-all and one-third octave band sound pressure levels were determined. This procedure was repeated on May 11, 1961. The results of those measurements and the calculated values for the same range are shown in Figure 12.

SECTION IV. DISCUSSION AND CONCLUSIONS

The anticipated over-all sound pressure levels may be raised or lowered several decibels by the prevailing weather conditions between the source and the receiver. Such meteorological focusing has been found to raise levels in rare instances 15 to 20 db. Also, no mention is made of the angular orientation with respect to the vehicle exhaust path. It is known that the directivity index of engines firing into a deflector bucket can vary 10 db or more at ranges up to several hundred feet, depending upon the angular orientation in the horizontal plane. Just what the long-range effect of such directivity is not yet known.

The results of the tests shown in Figure 12 demonstrate both the general accuracy of the prediction technique and the amount of variation from predicted levels to be expected for any single measurement. Certainly, while this procedure may be useful in predicting the general levels to be anticipated from static tests of large rocket vehicles, it should not replace actual measurement in areas of interest.

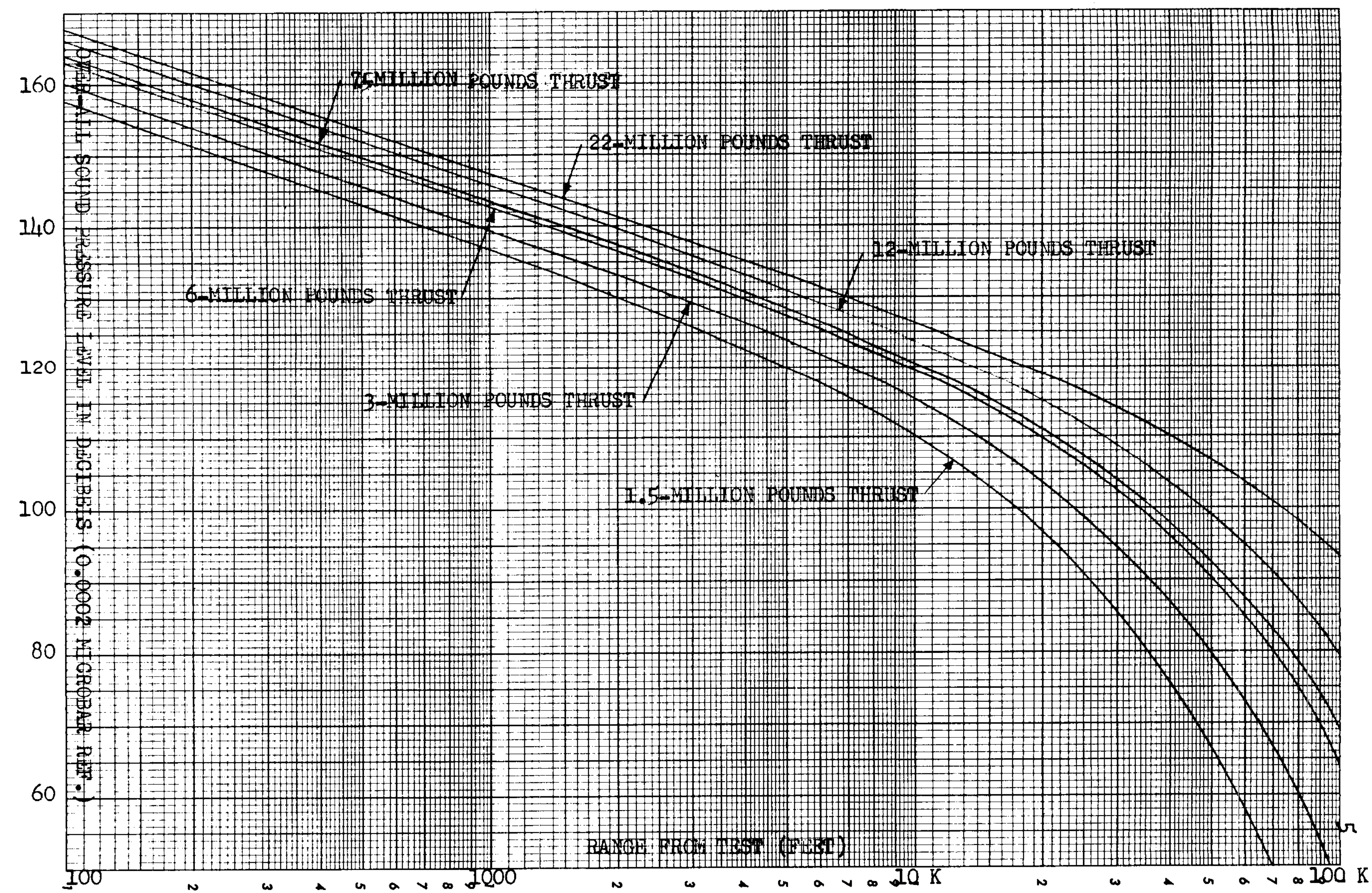

FIGURE 1. OVER-ALL SOUND PRESSURE LEVELS FROM LARGE VEHICLES AS A FUNCTION OF RANGE FROM TEST

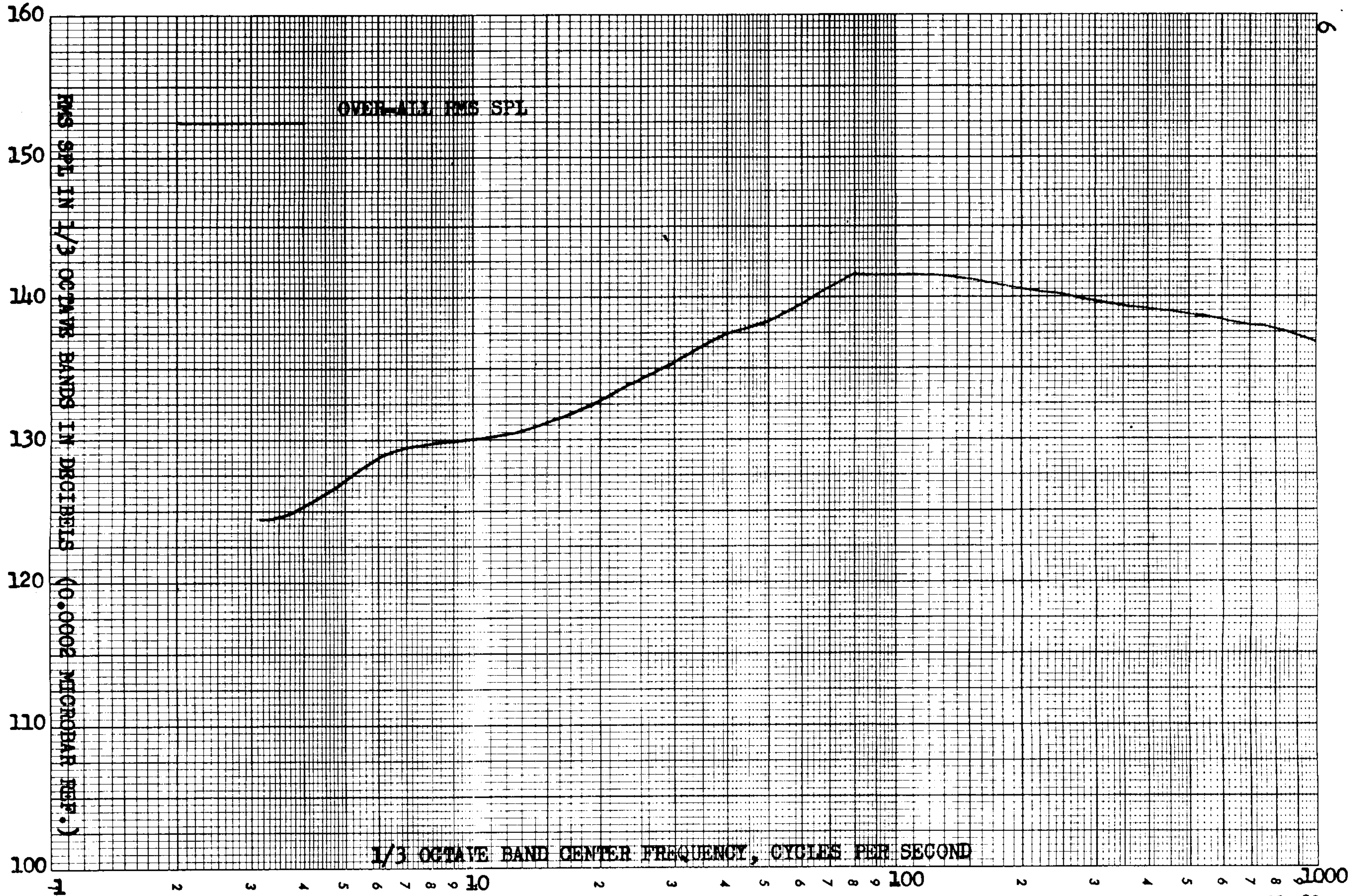

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FIGURE 2. MEASURED SOUND PRESSURE LEVELS FOR A 150-FOOT RADIUS (SATURN VEHICLE)

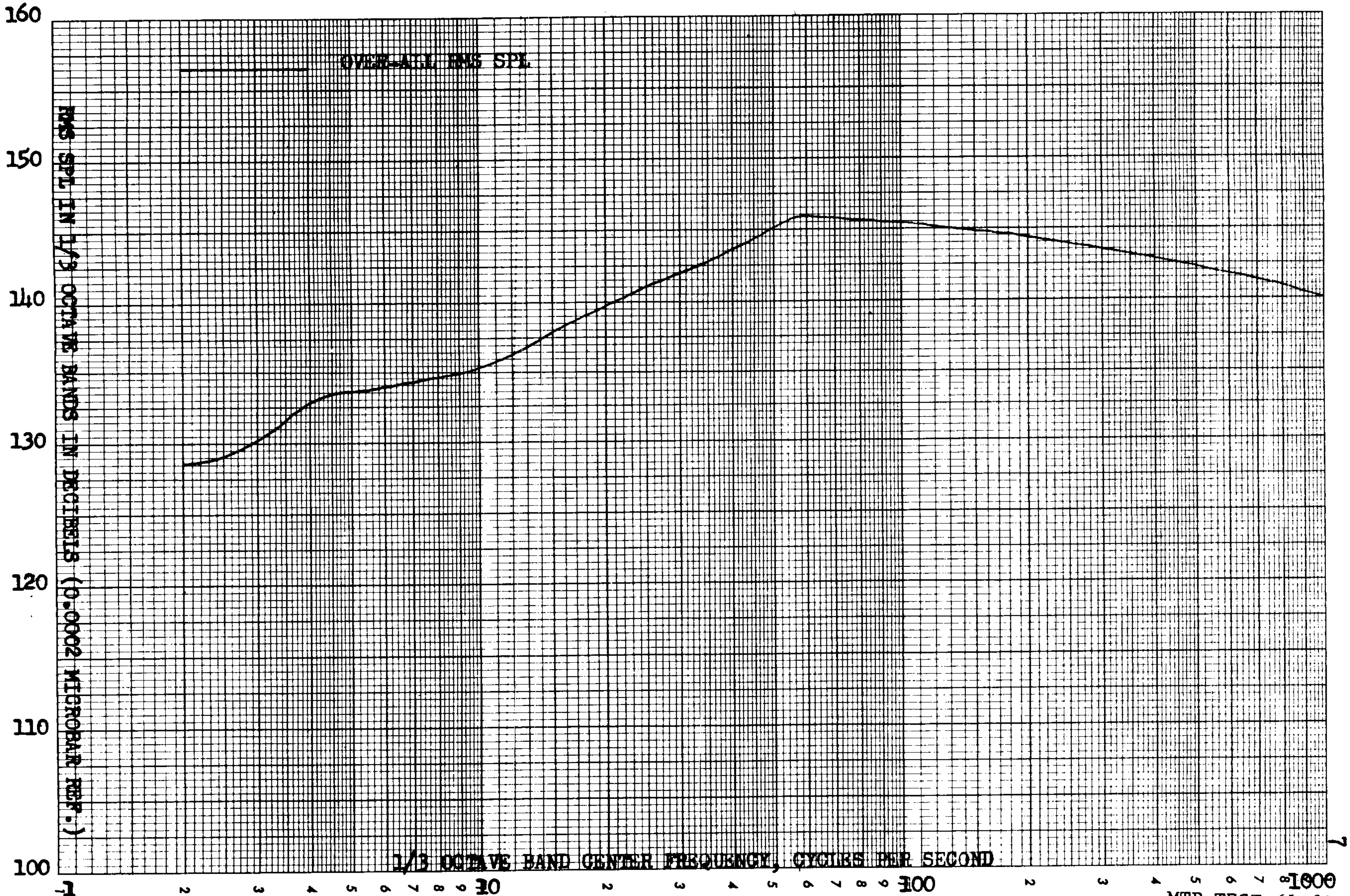

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FIGURE 3. ANTICIPATED SOUND PRESSURE LEVELS FOR A 150-FOOT RADIUS (3-MILLION POUND THRUST VEHICLE)

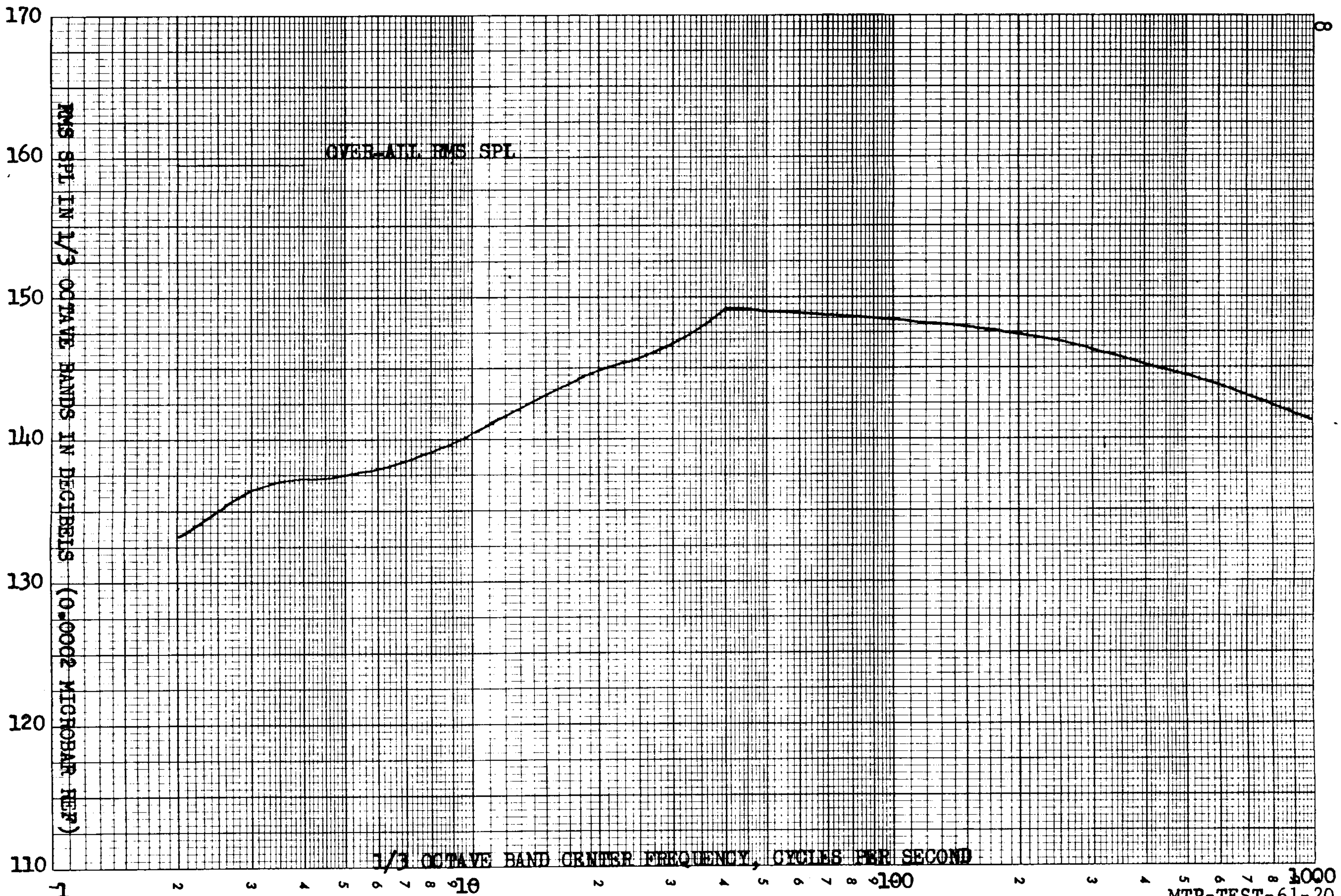

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FIGURE 4. ANTICIPATED SOUND PRESSURE LEVELS FOR A 150-FOOT RADIUS (6-MILLION POUND THRUST VEHICLE)

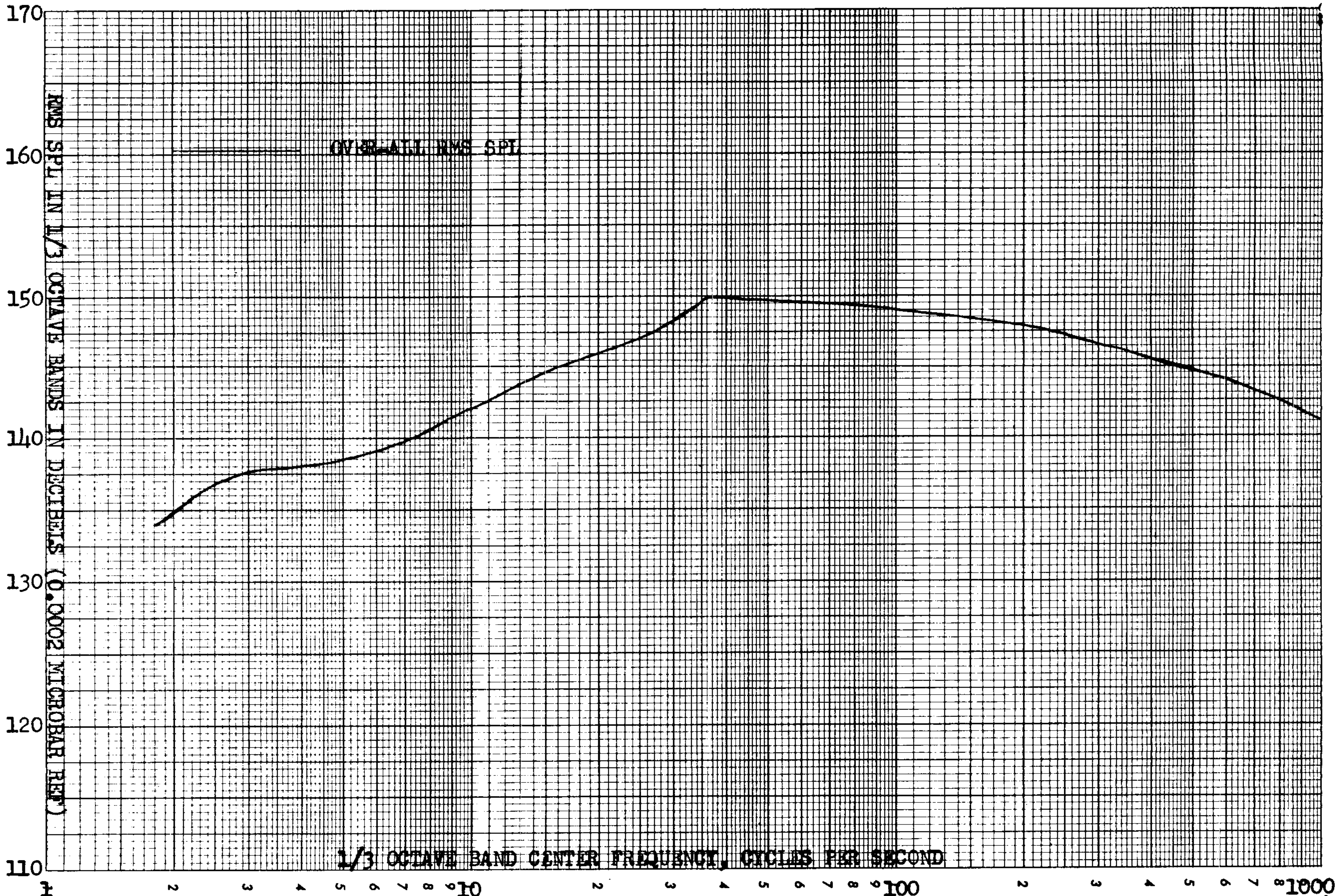

FIGURE 4A. ANTICIPATED SOUND PRESSURE LEVELS FOR A 150-FOOT RADIUS (7.5-MILLION POUND THRUST VEHICLE)

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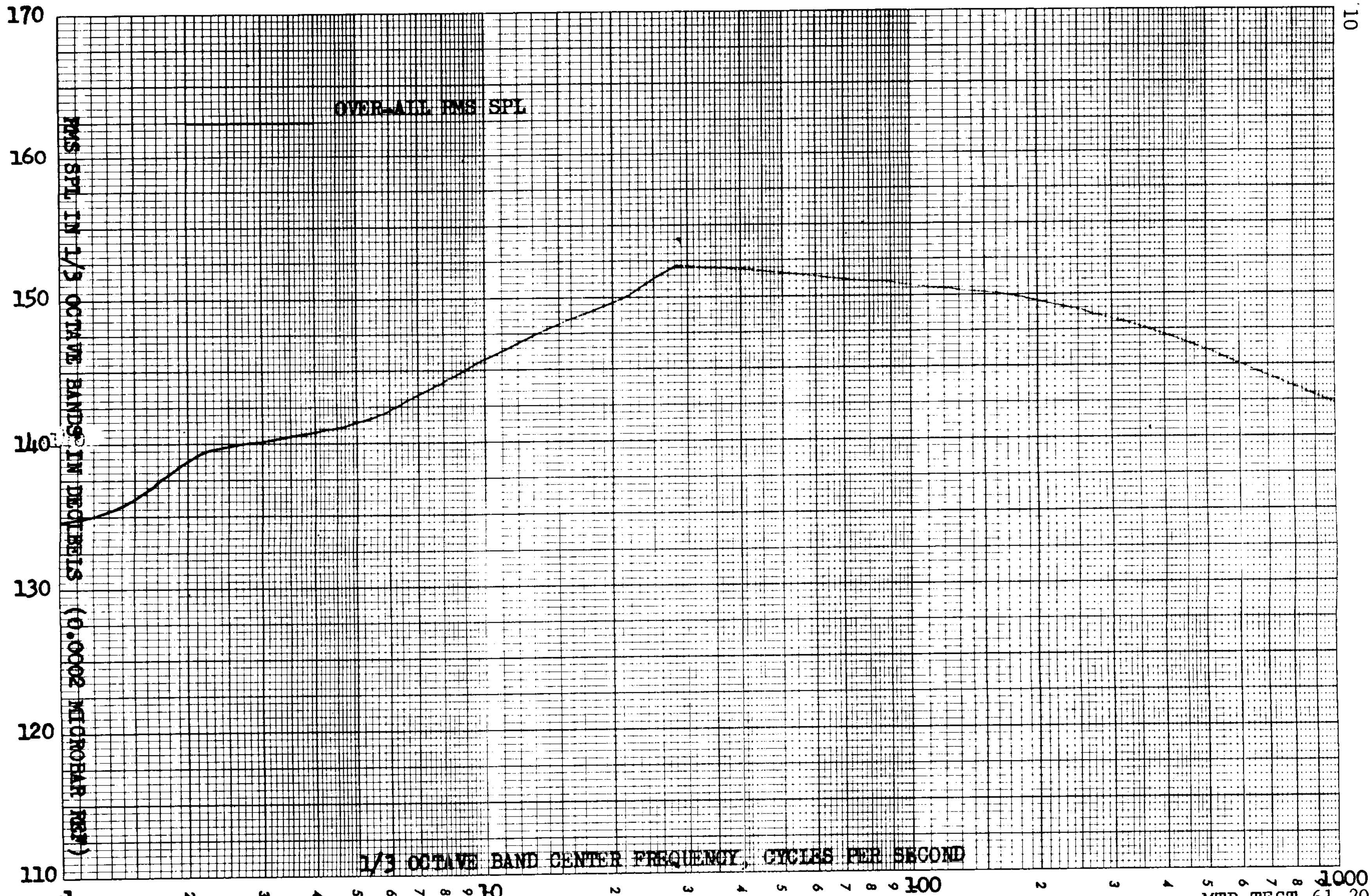

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FIGURE 5. ANTICIPATED SOUND PRESSURE LEVELS FOR A 150-FOOT RADIUS (12-MILLION POUND THRUST VEHICLE)

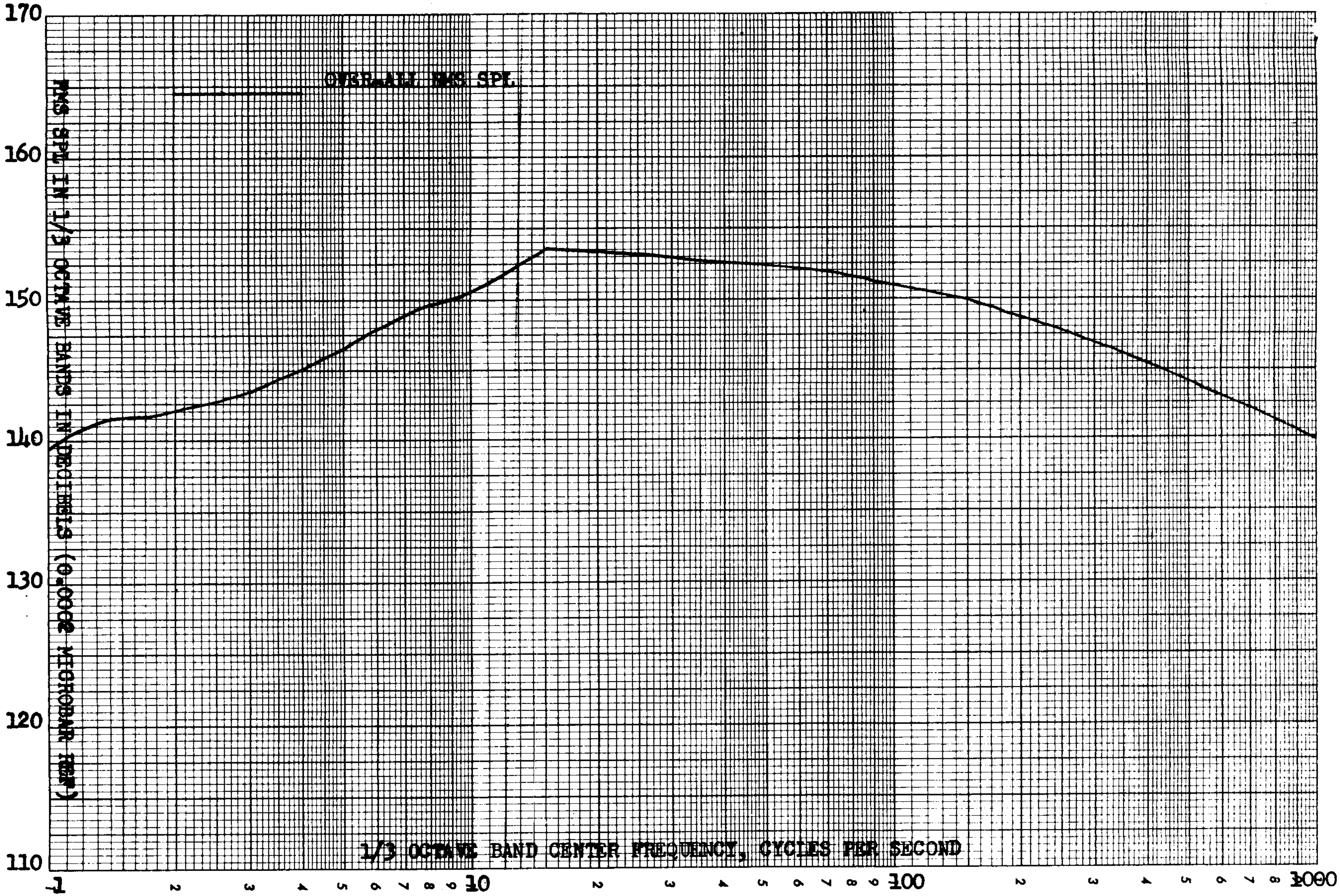

FIGURE 6. ANTICIPATED SOUND PRESSURE LEVELS FOR A 150-FOOT RADIUS (22-MILLION POUND THRUST VEHICLE)

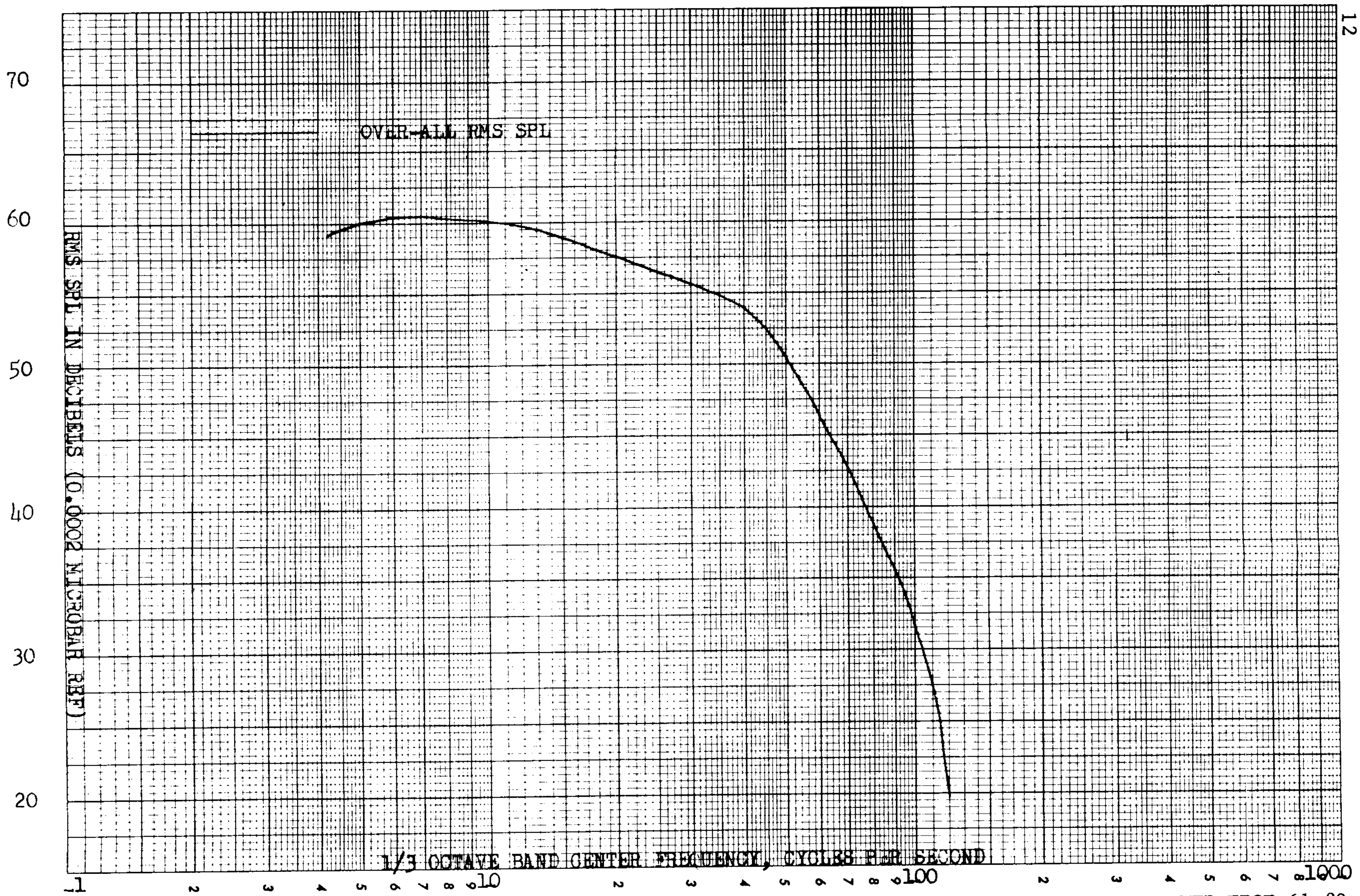

FIGURE 7. ANTICIPATED SOUND PRESSURE LEVELS FOR A 50,000-FOOT RADIUS (SATURN VEHICLE)

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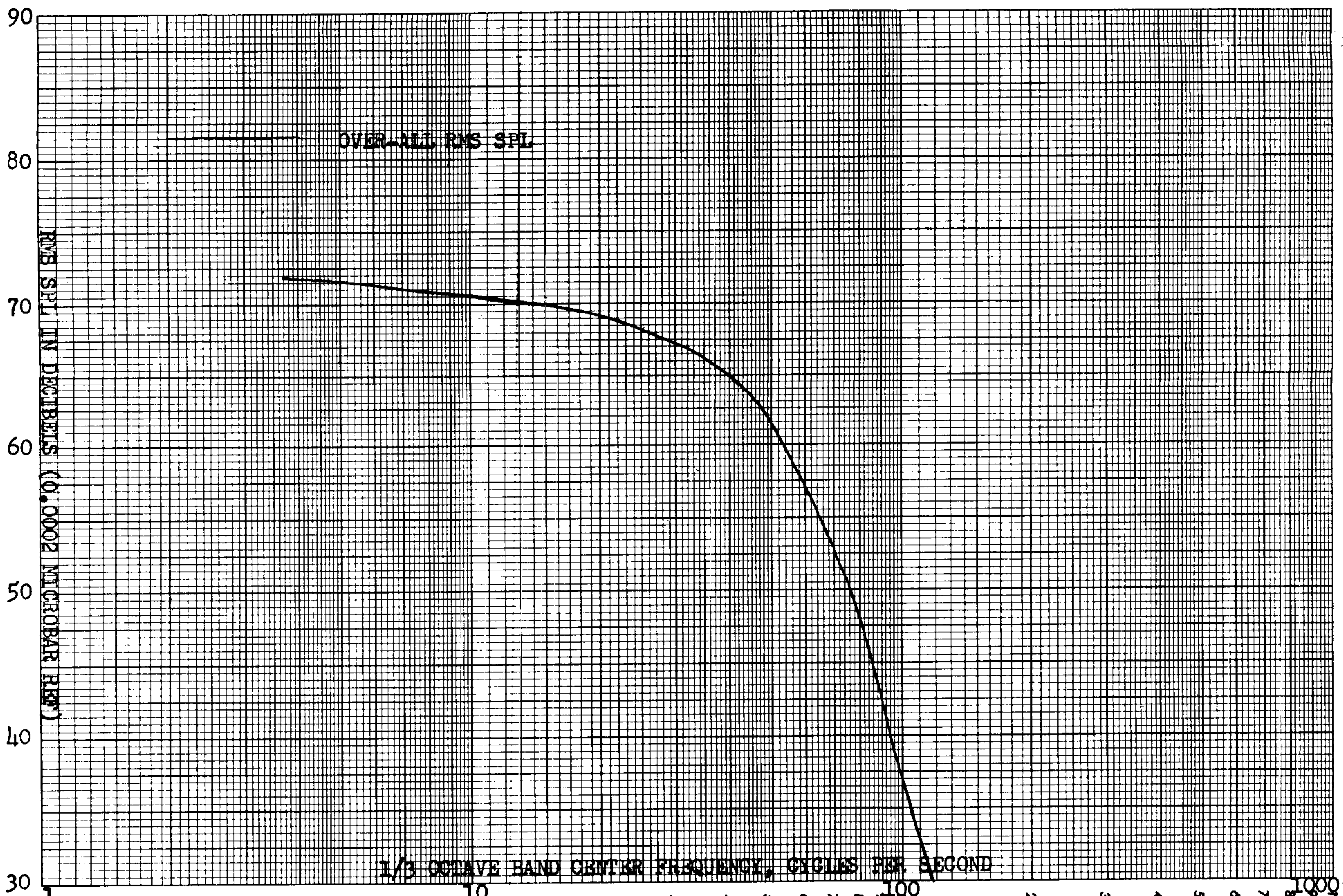

FIGURE 8. ANTICIPATED SOUND PRESSURE LEVELS FOR A 50,000-FOOT RADIUS (3-MILLION POUND THRUST VEHICLE)

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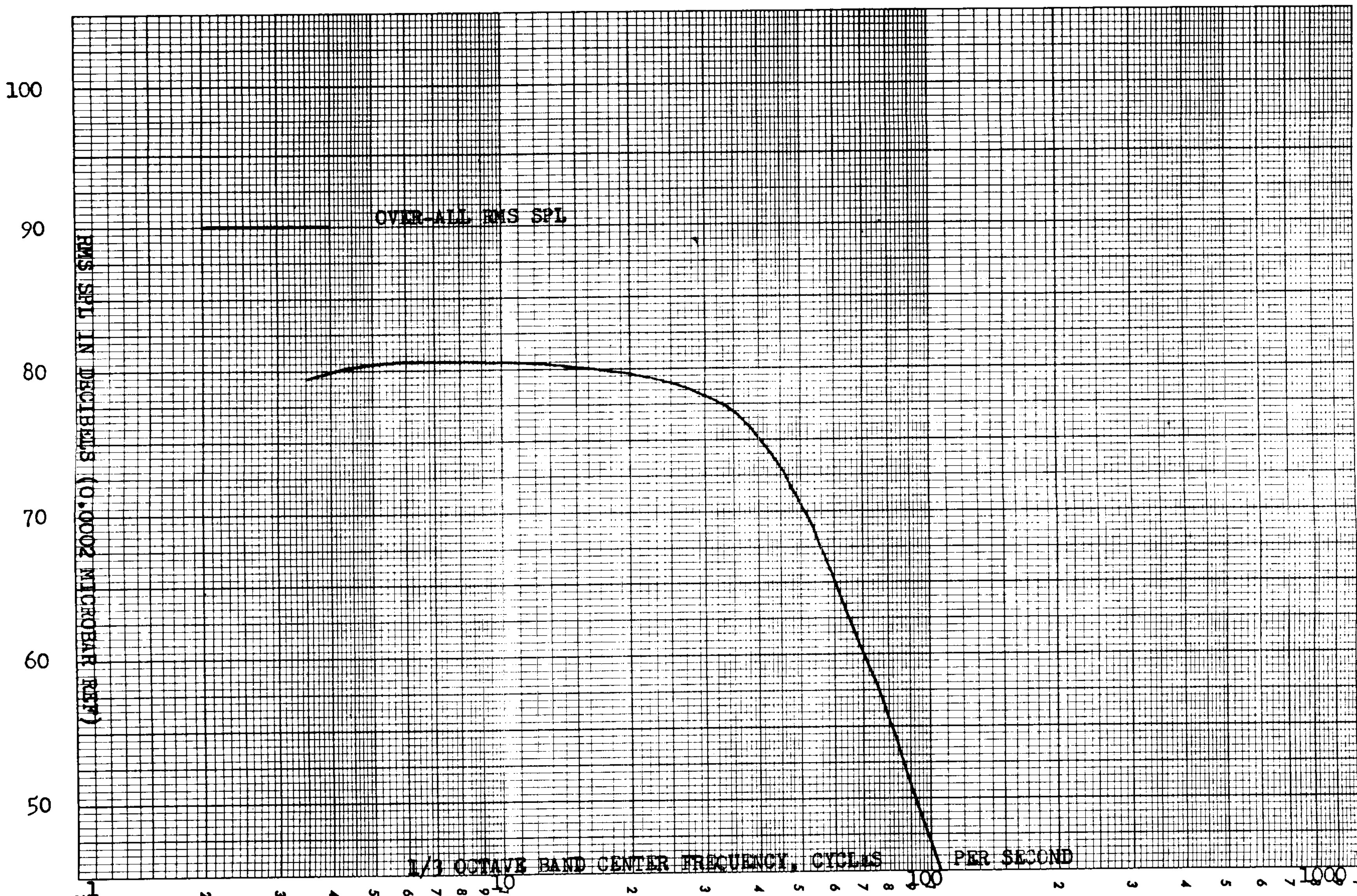

FIGURE 9. ANTICIPATED SOUND PRESSURE LEVELS FOR A 50,000-FOOT RADIUS (6-MILLION POUND THRUST VEHICLE)

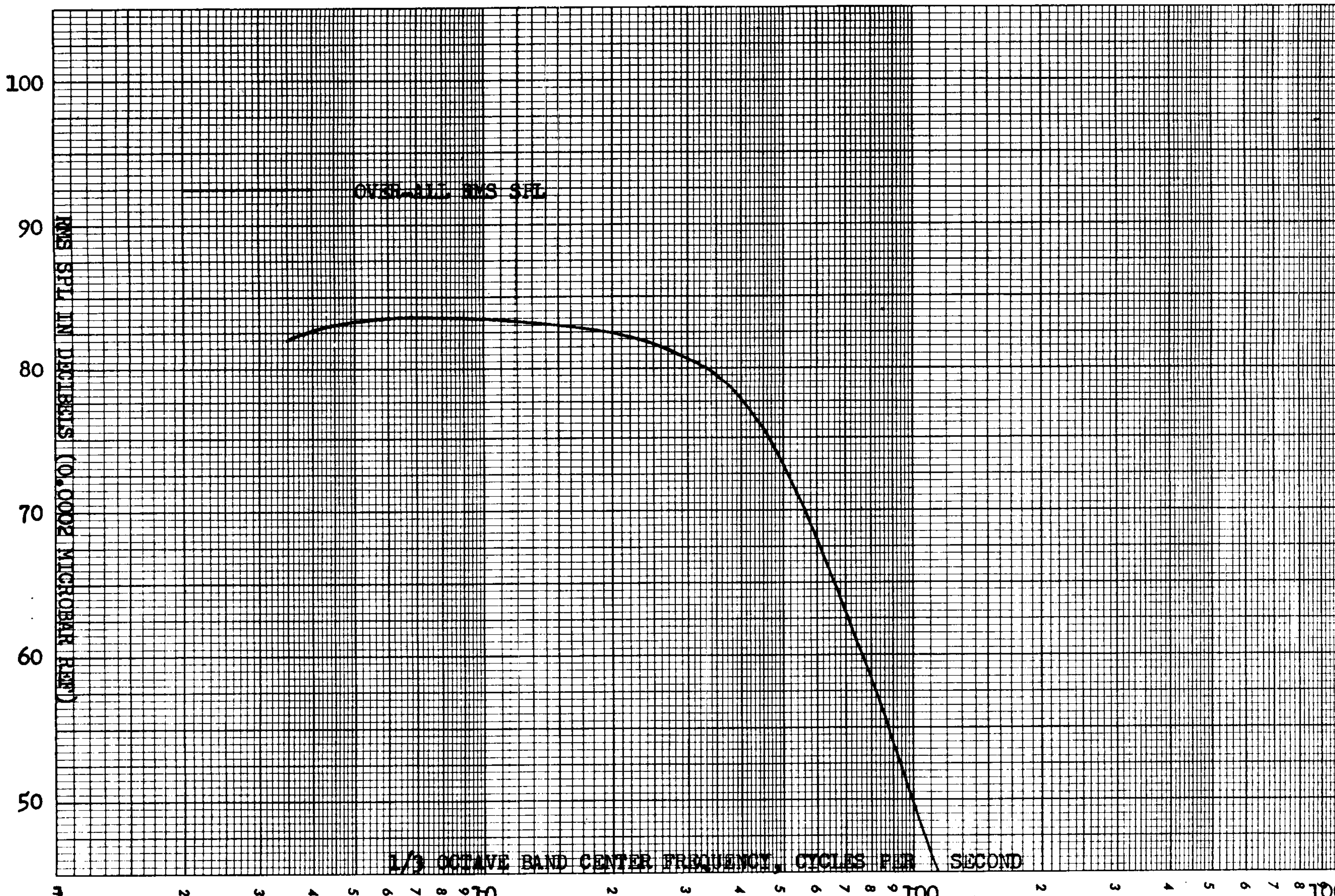

FIGURE 9A. ANTICIPATED SOUND PRESSURE LEVELS FOR A 50,000-FOOT RADIUS (7.5-MILLION POUND THRUST VEHICLE)

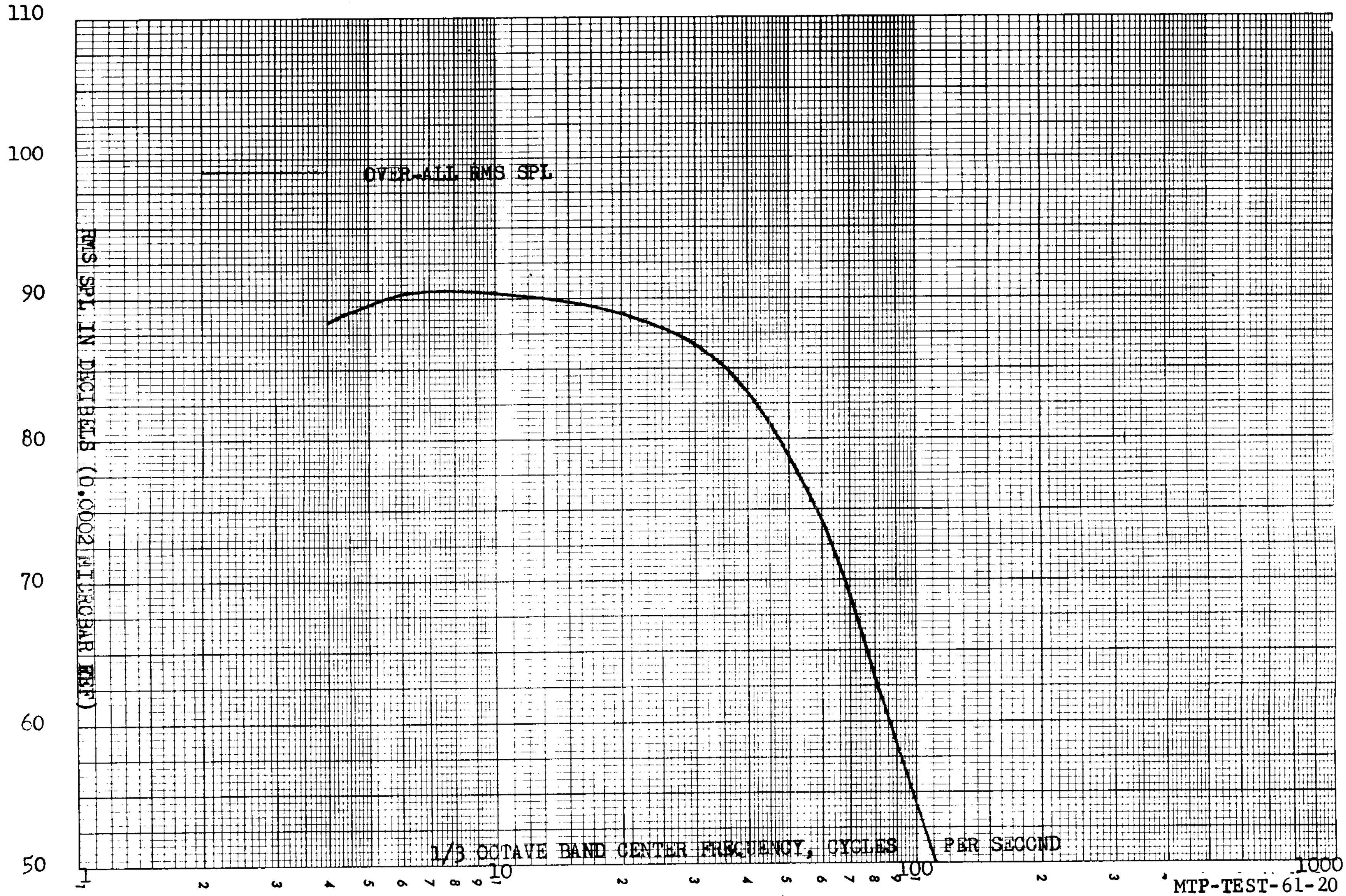

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FIGURE 10. ANTICIPATED SOUND PRESSURE LEVELS FOR A 50,000-FOOT RADIUS (12-MILLION POUND THRUST VEHICLE)

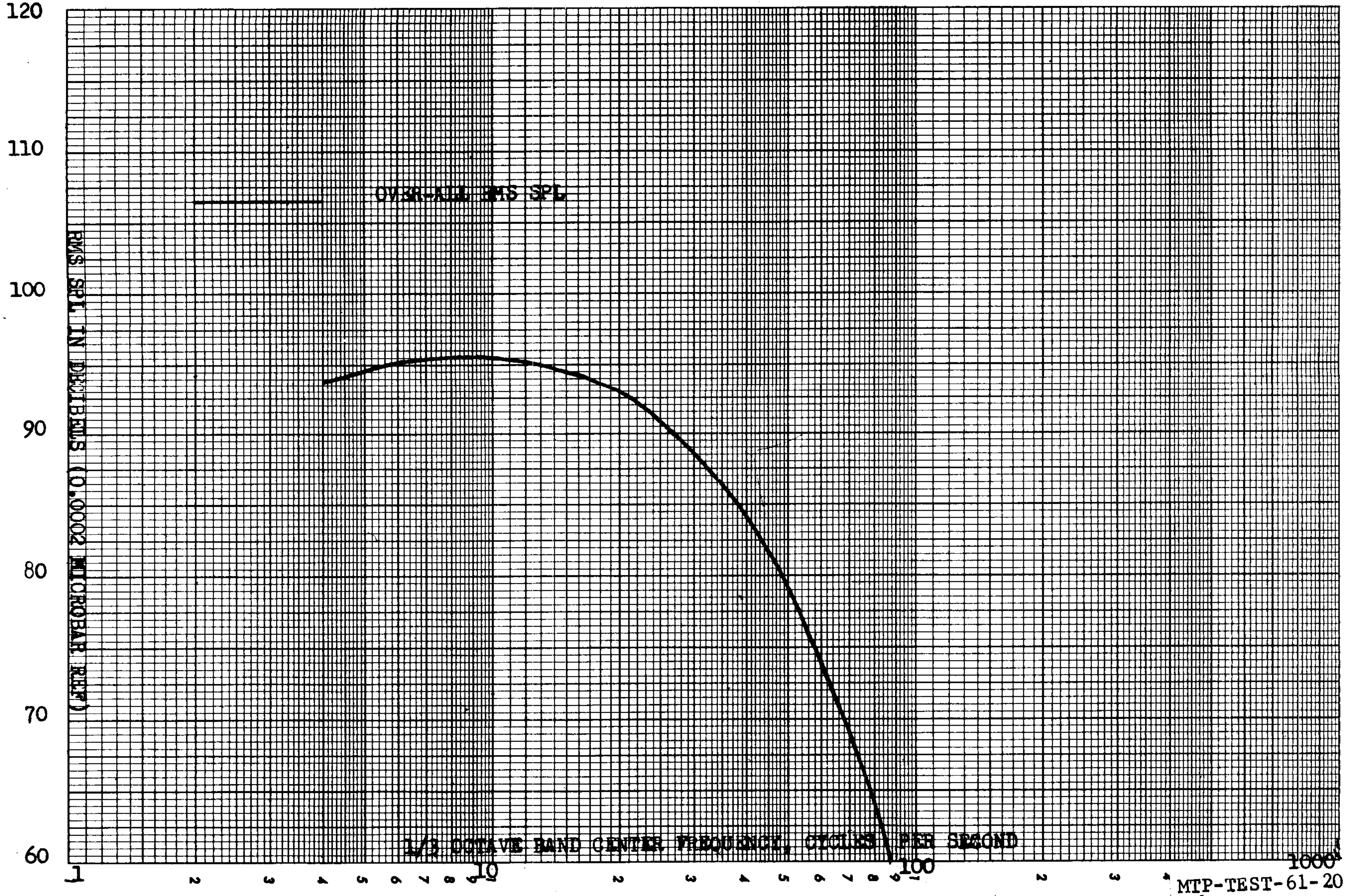

FIGURE 11. ANTICIPATED SOUND PRESSURE LEVELS FOR A 50.000-FOOT RADIUS (22-MILLION POUND THRUST VEHICLE)

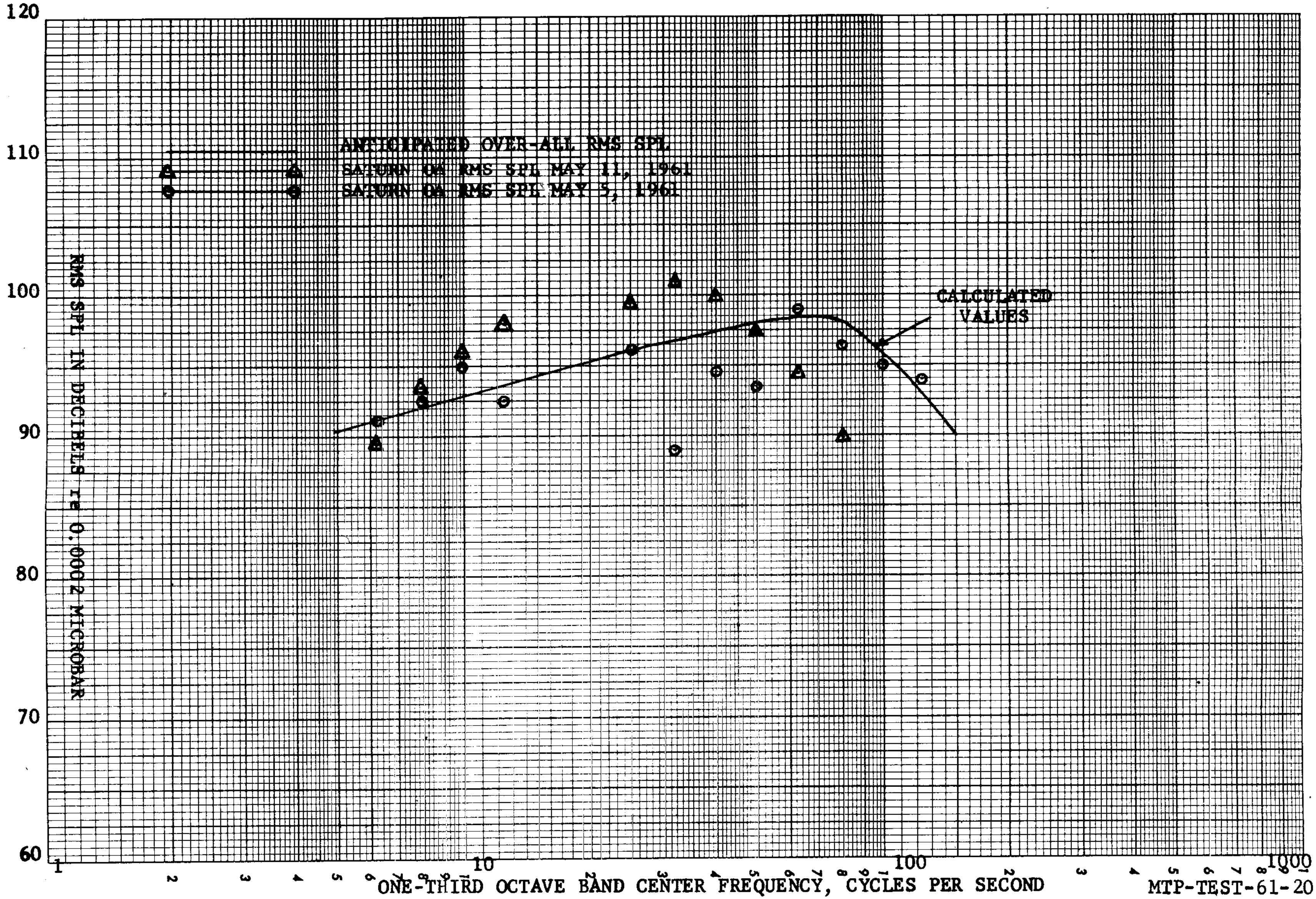

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FIGURE 12. MEASURED & ANTICIPATED SOUND PRESSURE LEVELS FOR A 10,000-FOOT RADIUS (SATURN VEHICLE)

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MTP-TEST-61-20
November 22, 1961

APPROVAL

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